Dependence of some measured radar emission spectra on measurement (IF) bandwidth

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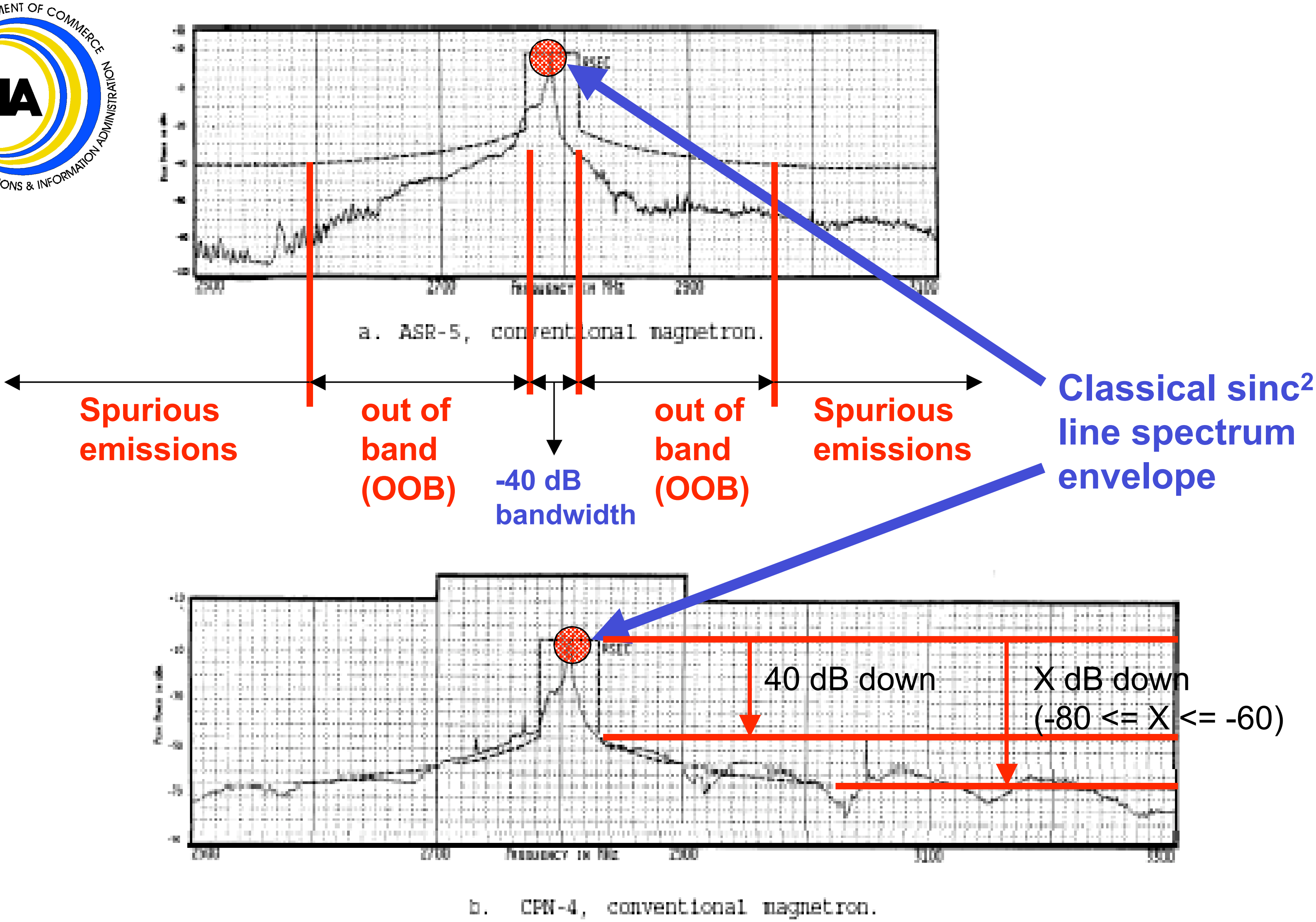
Introduction

Emissions: Radar transmitters produce measurable emissions far outside the classical sinc^2 spectrum. These are called *out-of-band* and *spurious*.

Emission masks: Out-of-band (OOB) and spurious emission levels of Government radars are regulated in the United States by the NTIA *Radar Spectrum Engineering Criteria* (RSEC). Other masks may be specified for non-Government radars and radars of other Administrations.

Specification: Some emission masks specify suppression levels in decibels *relative* to the peak power at radar fundamental frequency.

Subtlety: Absolute power is measured at radar fundamental frequencies, but spectral power density is measured in the OOB and spurious regions. This leads to an interesting phenomenon…


a. ASR-5, conventional magnetron.
Spurious emissions
out of band (OOB)
-40 dB bandwidth
out of band (OOB)
Spurious emissions
Classical sinc^2 line spectrum envelope
40 dB down
X dB down
(-80 <= X <= -60)
b. CPN-4, conventional magnetron.

The Problem

Measurement Bandwidth: Emission spectra are convolved with measurement system response functions. For this project, these are bandwidths (3 dB, gaussian-shaped IF) of a spectrum analyzer.

Measured power at the radar fundamental varies as 20 log of the measurement bandwidth, up to the point that measurement bandwidth (B_m) exceeds emission bandwidth (B_e), (approximately 1/pulse width).

Measured power (density) in the OOB and spurious regions continues to increase when $B_m > B_e$. Furthermore, the 20 log relationship does not necessarily hold. Some references claim that OOB and spurious emissions are "noise-like" and should therefore vary as 10 log (B_m).

Question: How do OOB and spurious emissions vary with B_m? 10 log, 20 log, or somewhere in between? Somewhat equivalent question is, how noise-like *are* OOB and spurious emissions?

Approach

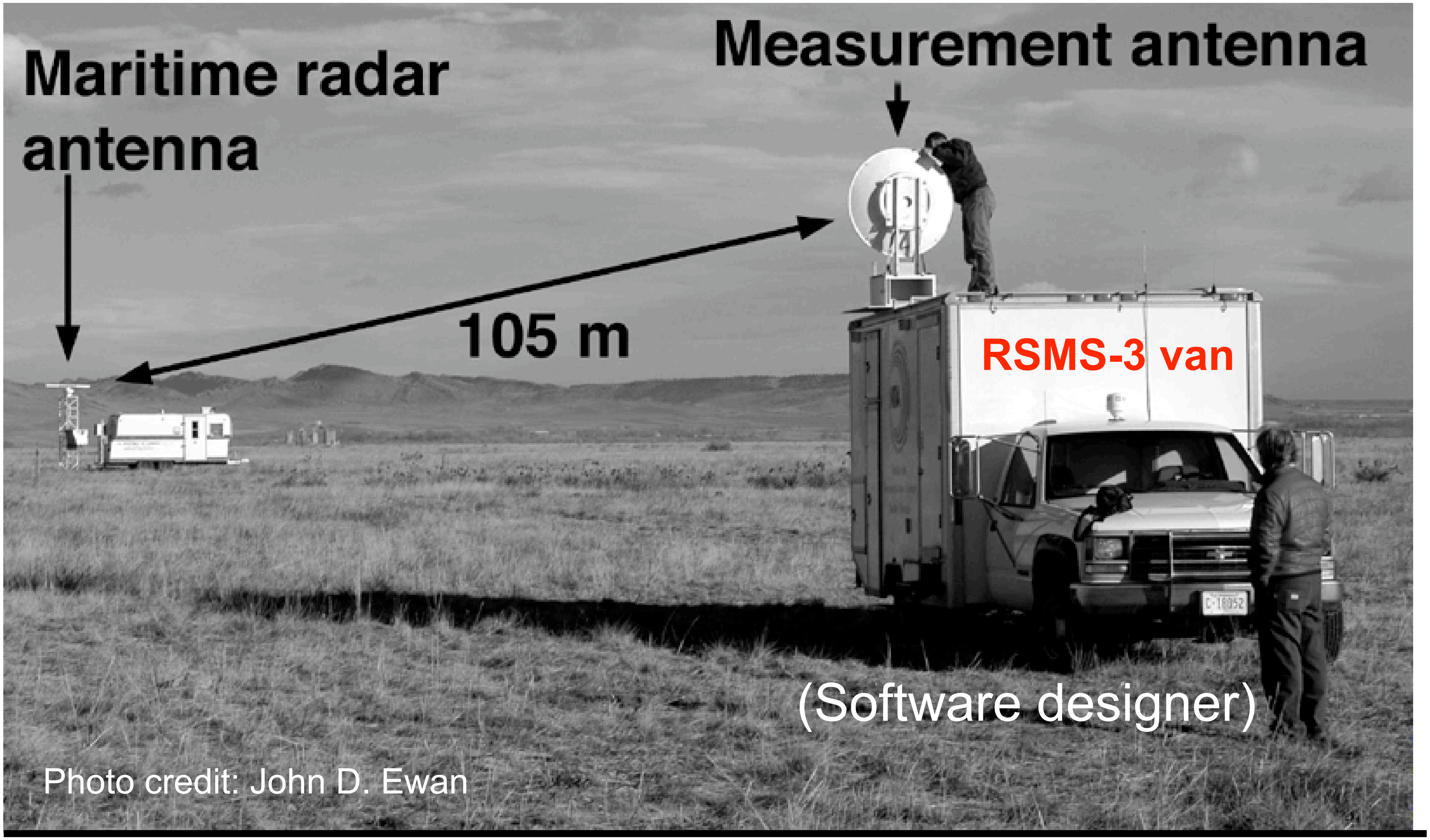
Theoretical modeling of radar spurious emissions may have much to offer, but the required level of effort was beyond our immediate resources (especially the amount of time available to finish the work).

Instead, we decided to employ an empirical approach for our effort.

We measured the emission spectrum of a single radar in multiple bandwidths and then determined how much the measured OOB and spurious emissions varied with B_m.

More detailed studies may follow, but this work represents a initial examination of this question in a systematic way.

Measurement



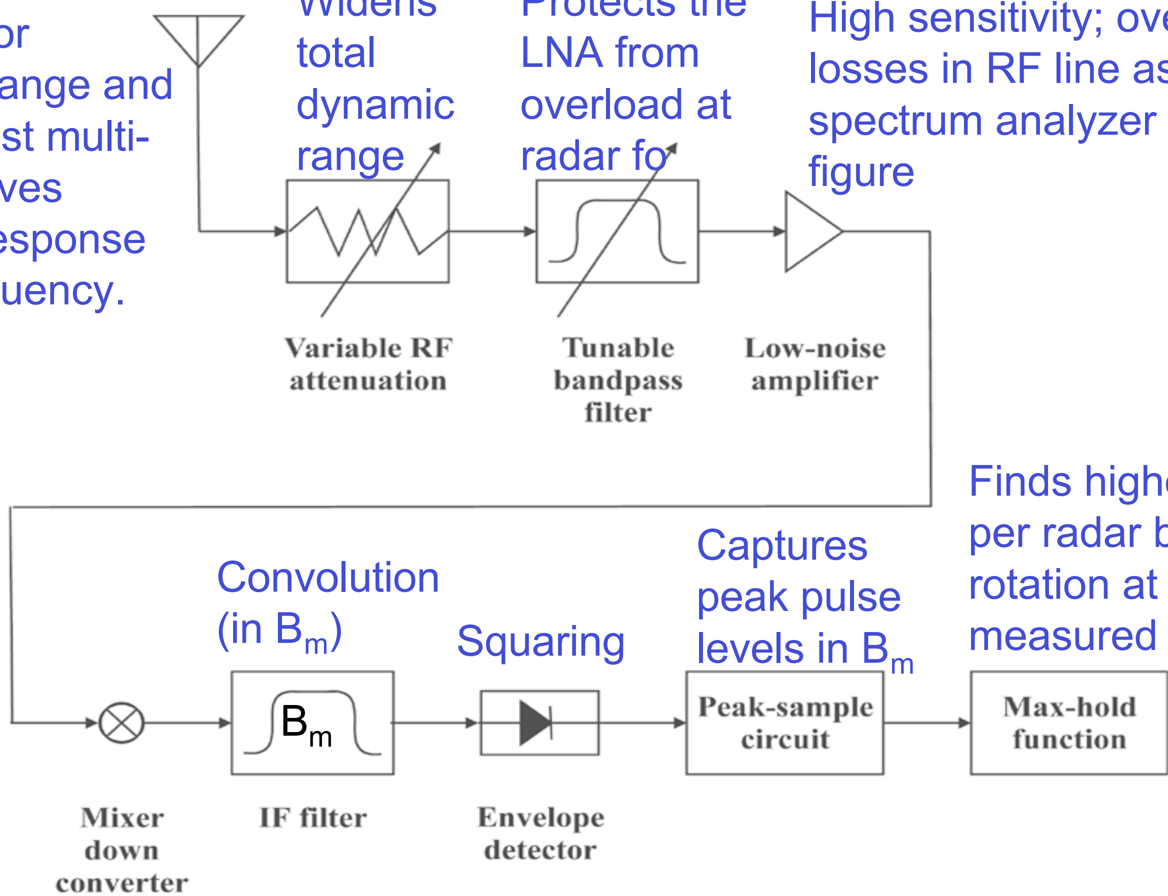
Measurement system functional block diagram

Parabolic antenna for improved dynamic range and discrimination against multi-path effects. Also gives constant-aperture response as a function of frequency.

Widens total dynamic range

Protects the LNA from overload at radar fo

High sensitivity; overdrives losses in RF line as well as spectrum analyzer noise figure



Convolution (in B_m)

Squaring

Captures peak pulse levels in B_m

Finds highest pulse per radar beam rotation at each measured frequency

Stepped Mode Measurements

- Basic strategy is to *step* (in a series of zero-hertz time slices) across a frequency range. Each time slice is a little longer than the radar beam rotation interval (about 2.6 seconds for this radar).

- Measurement performed under computer control of spectrum analyzer as described in Direct Method sections of M.1177-2.

- Available dynamic range for the measurement system was about 60 dB (spectrum analyzer) plus 70 dB (front-end attenuator), for a total of 130 dB dynamic range.

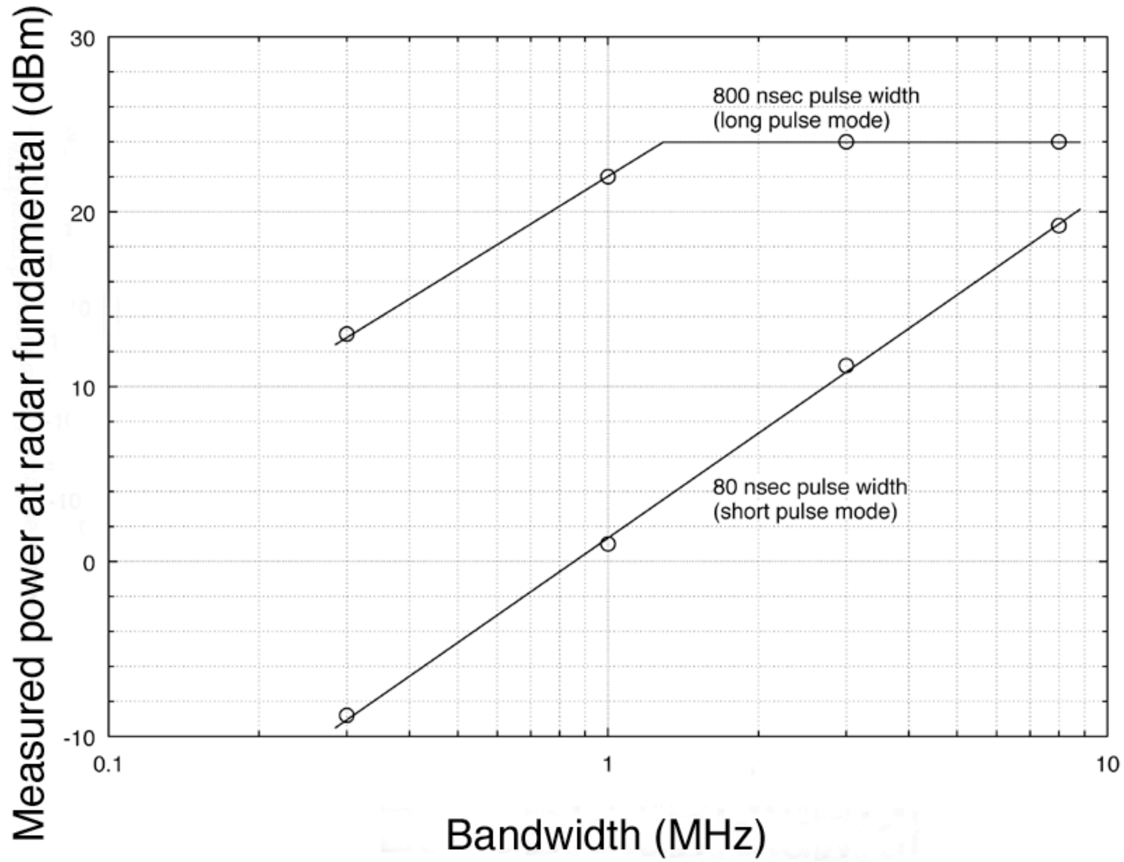
Measurement Variables

 The results presented here show measured variation in measured power levels of fundamental, OOB and spurious emissions of a maritime X-band surface search radar as a function of the following measurement bandwidths:

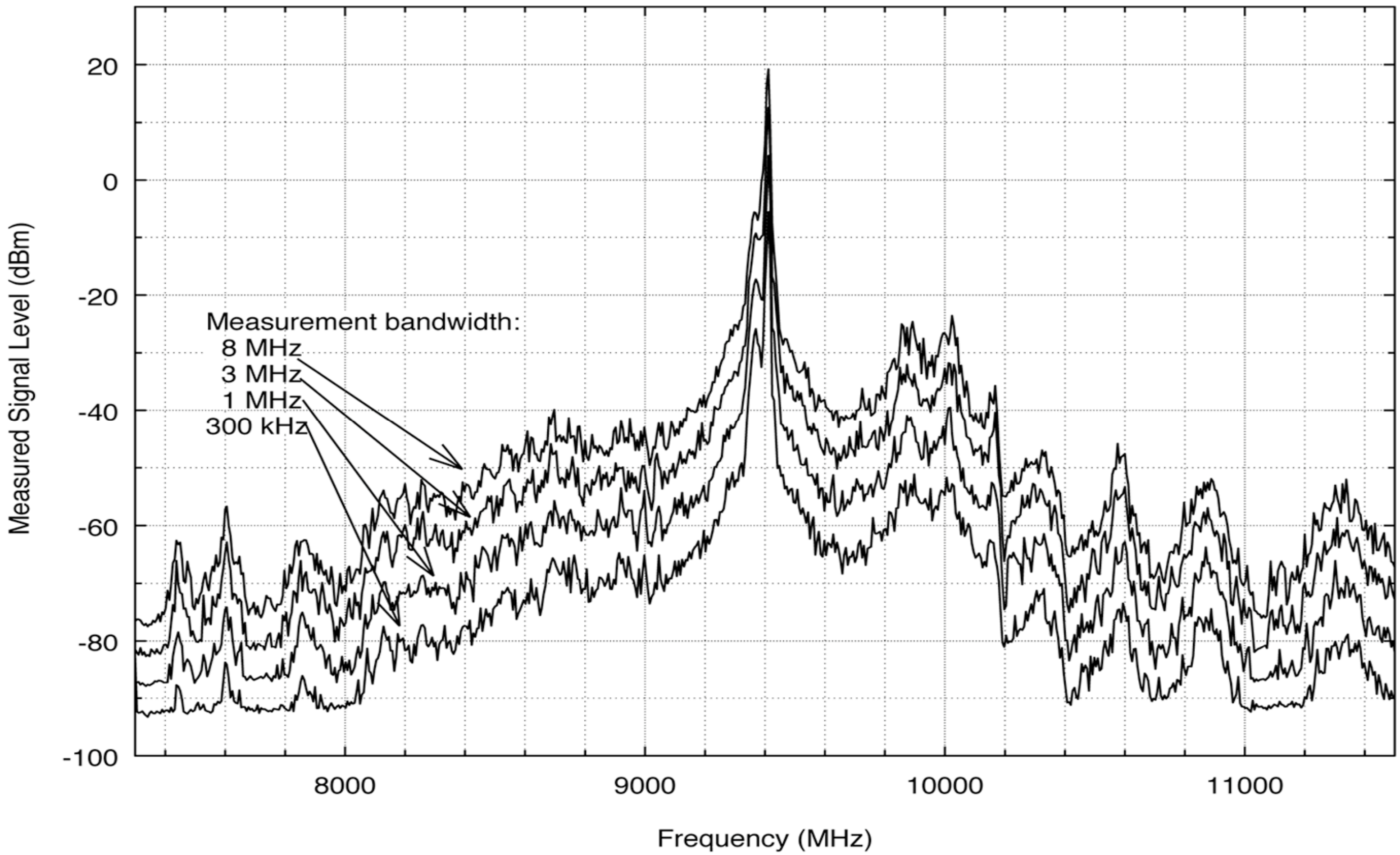
300 kHz, 1 MHz, 3 MHz, and 8 MHz.

 All bandwidth-variation measurements were repeated for two radar operational modes: **short pulse** (80 ns pulse width specified) and **long pulse** (830 ns pulse width specified). Interestingly, the measured pulse widths were about 30 ns longer than specified in the radar operations manual (ie., they were 110 ns and 830 ns).

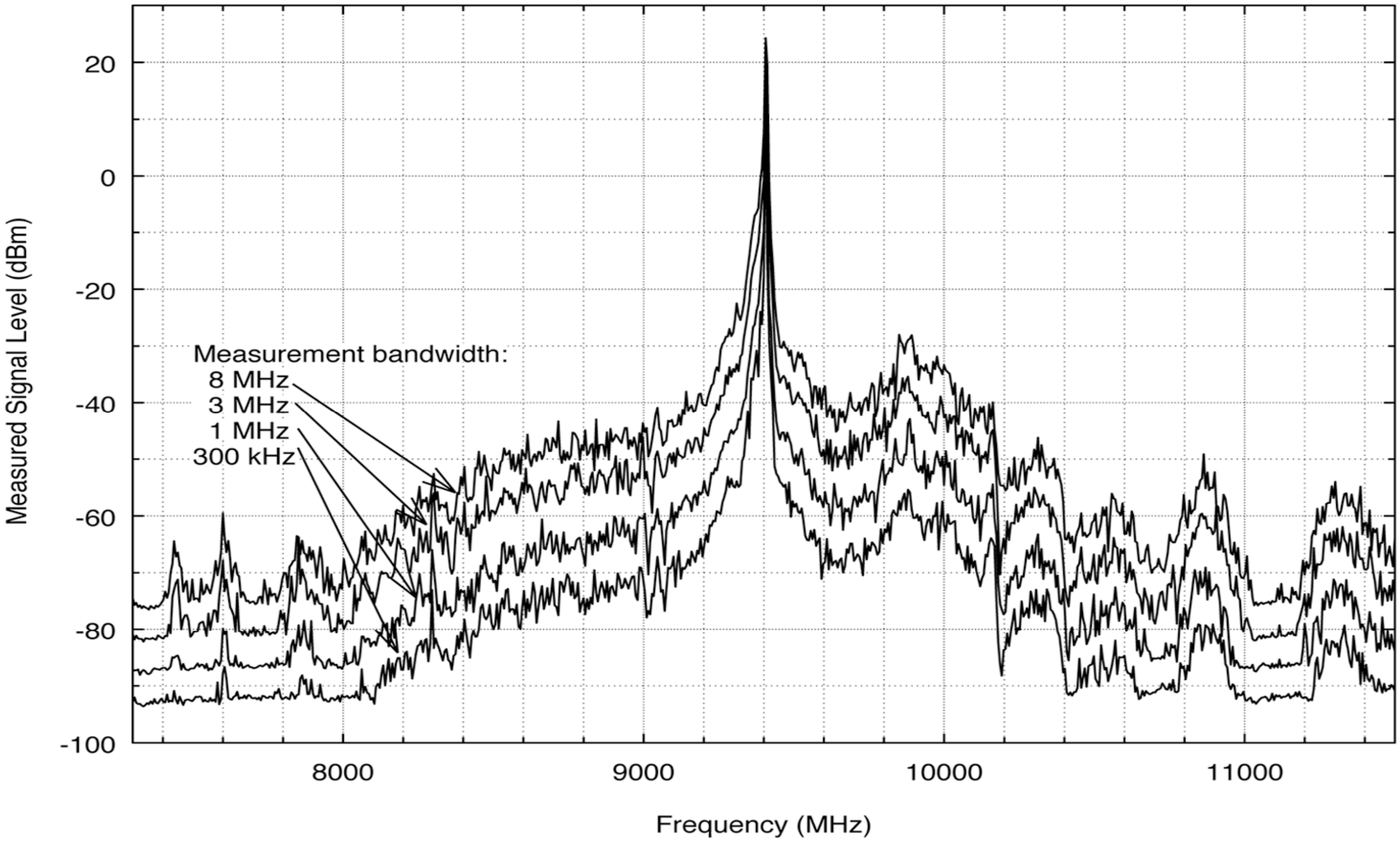
Variation in measured power at radar fundamental as function of measurement bandwidth & pulse mode



Radar emission spectra measured in four bandwidths, short-pulse mode



Radar emission spectra measured in four bandwidths, long-pulse mode



Analysis: Quantify deviation from 20 log progression with B_m

$$\Delta = \left[\frac{P_x - P_y}{\log\left(B_x / B_y\right)}\right] - 20 \qquad \text{(unitless)}$$

Where:

Delta = deviation from 20log(B_m) progression;
$P_{[x,y]}$ = log power measured in B_x and $B_{y;}$
$B_{[x.y]}$ = measurement bandwidth;
[x,y] are subscripts for successive measurement IF bandwidths (e.g., 3 MHz and 1 MHz)

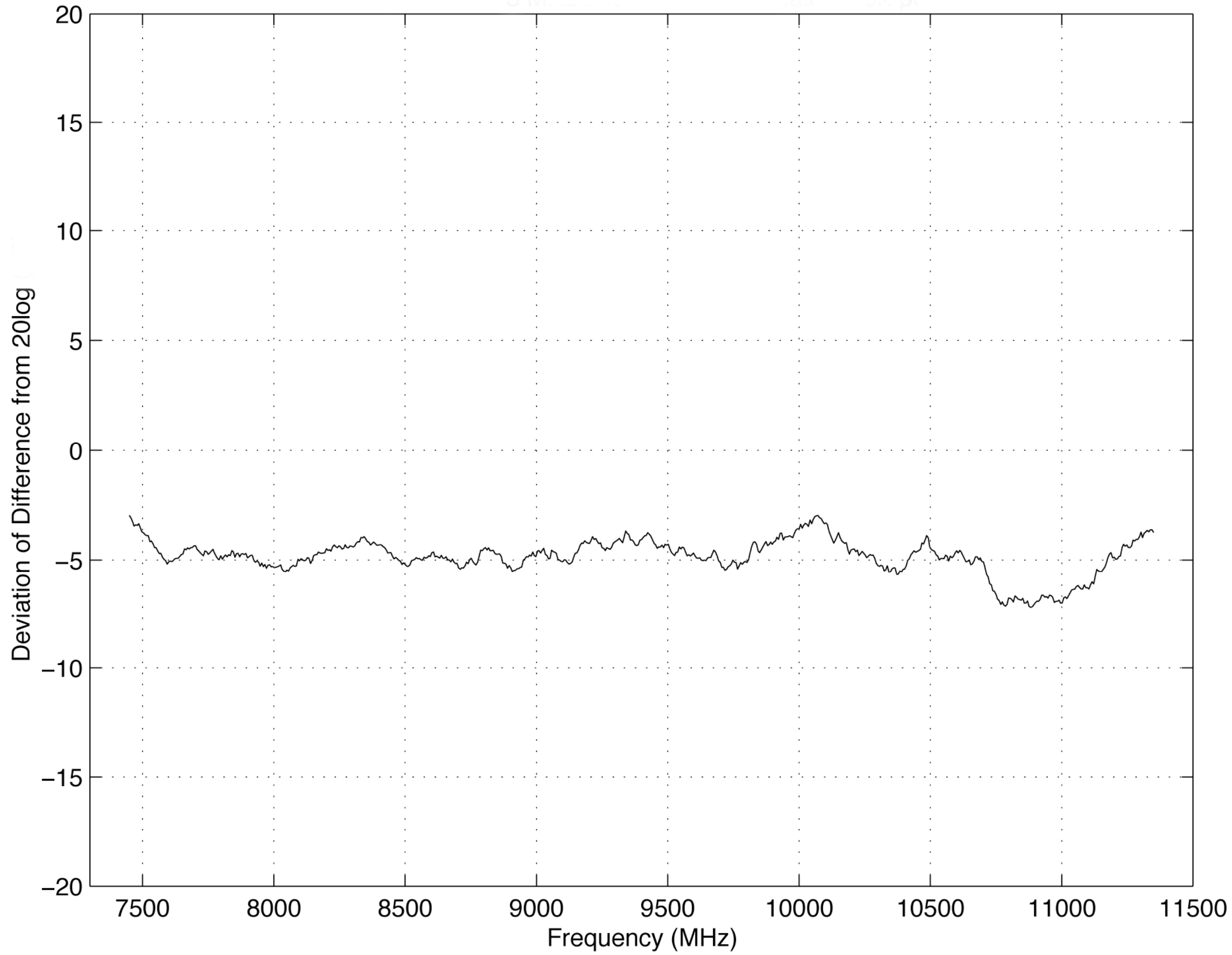
Additional technical details

1) All measurements were repeated on exactly the same set of 700 frequencies between 7300-11500 MHz, so that we could legitimately subtract measured values between successive curves.

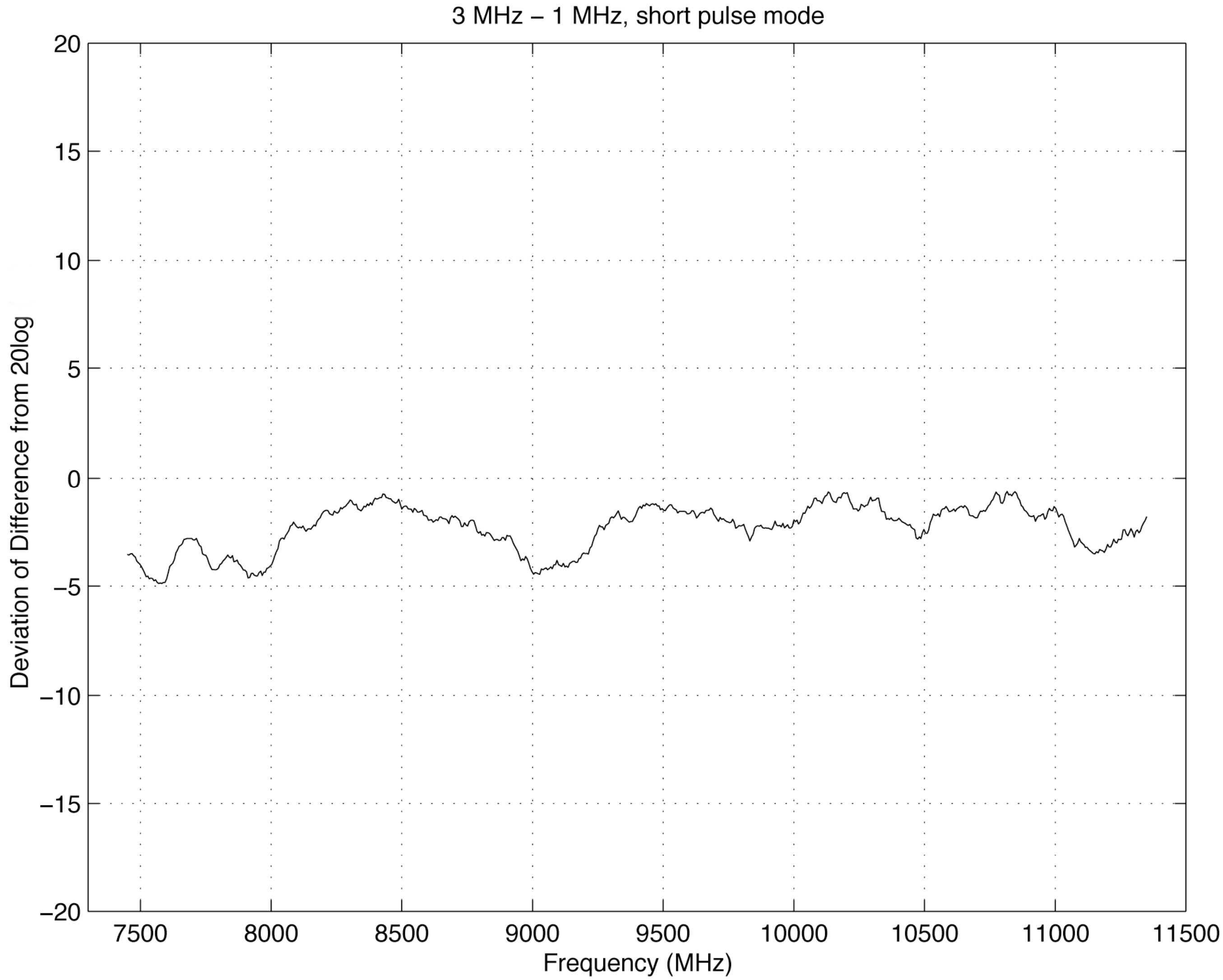
2) Measurement step size was 6 MHz. But detailed measurements were made near the radar fundamental frequency in step sizes equal to measurement bandwidths to ensure that we accurately measured peak power at f_0 in the measurement bandwidth.

3) Point-to-point differences between the curves were somewhat difficult to read graphically (looked spiky). To make interpretation easier, we used a 50-point-wide sliding window to smooth the differences between the curves.

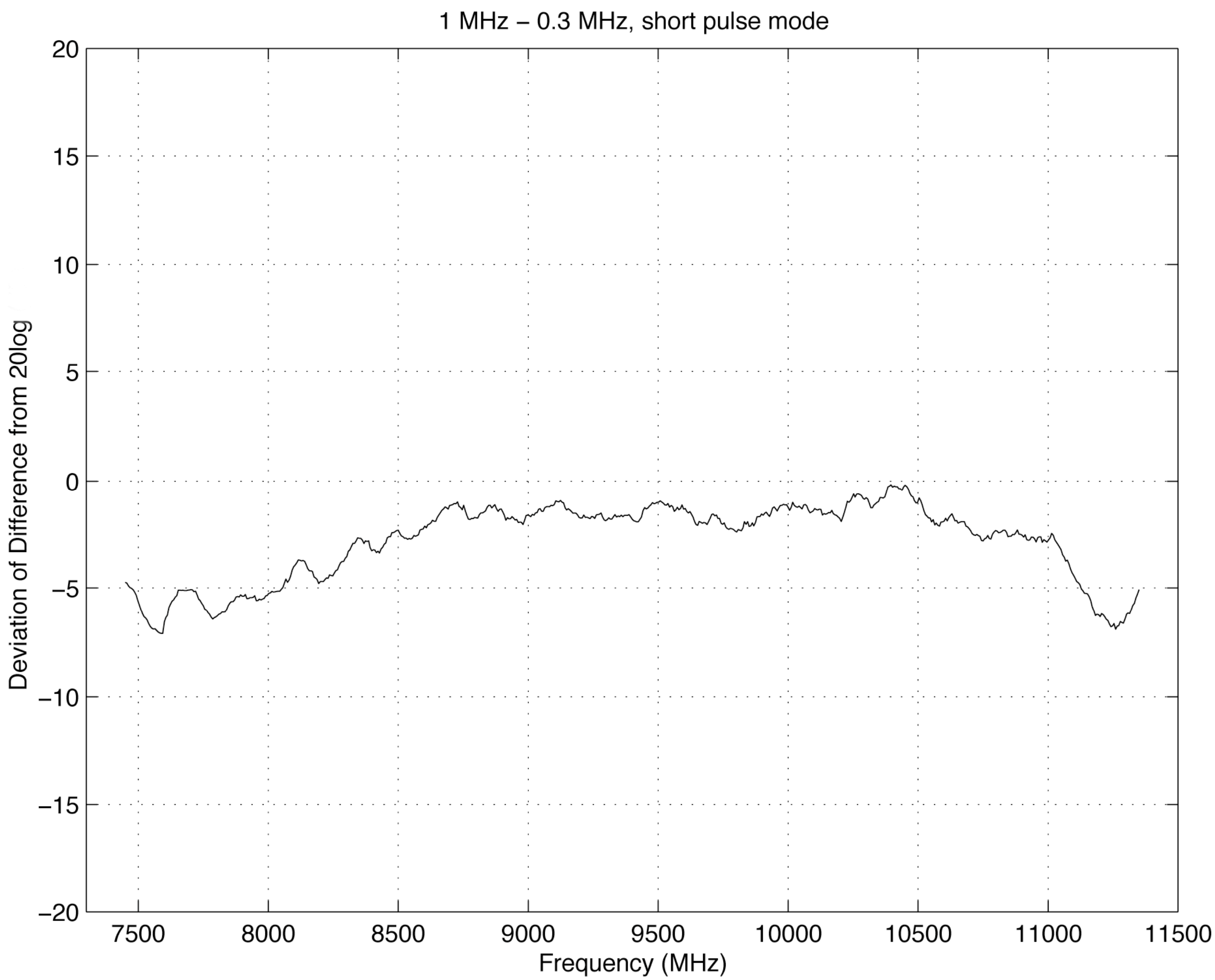
Difference: 8 MHz-3 MHz short pulse mode



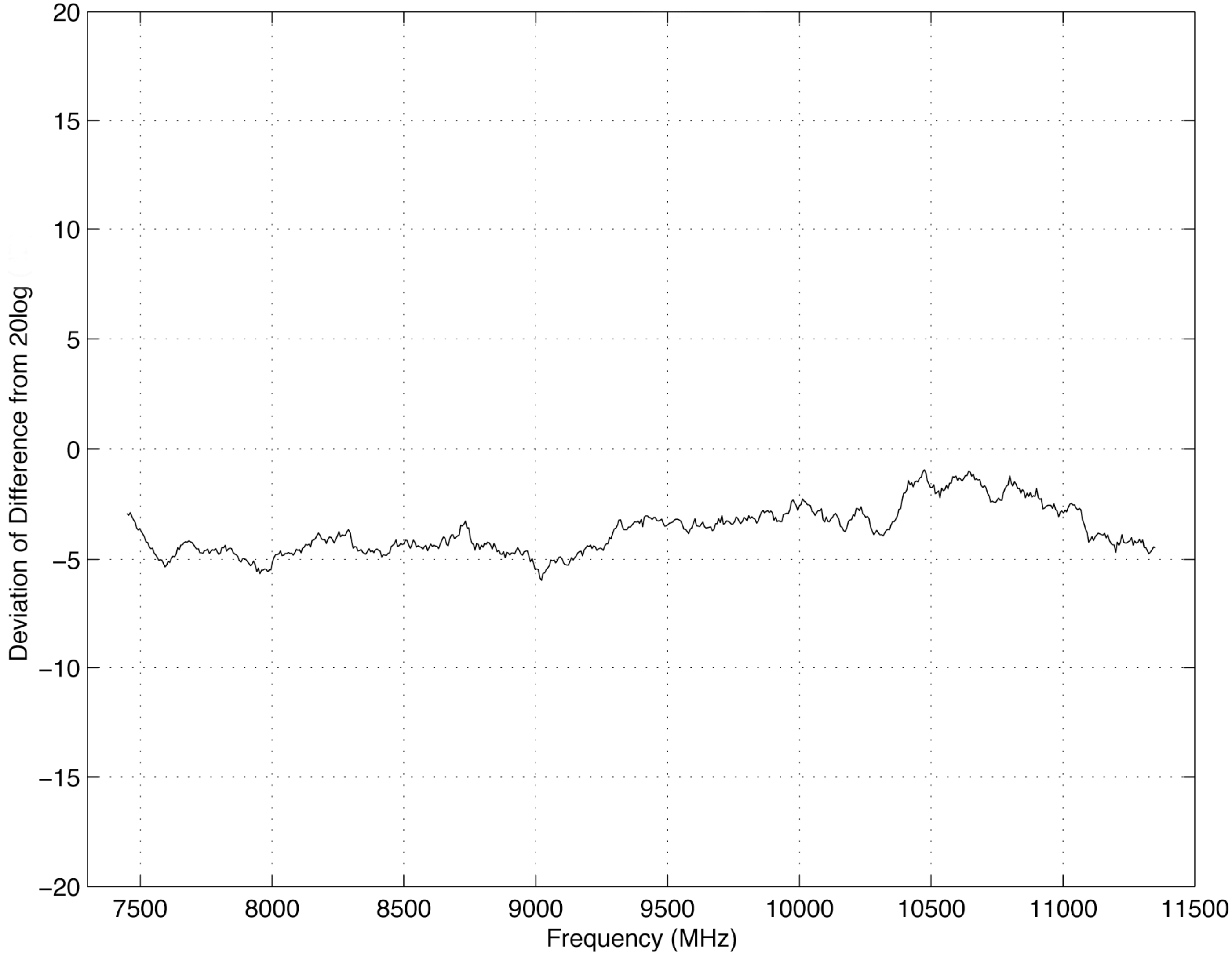
Difference: 3 MHz-1 MHz short pulse mode



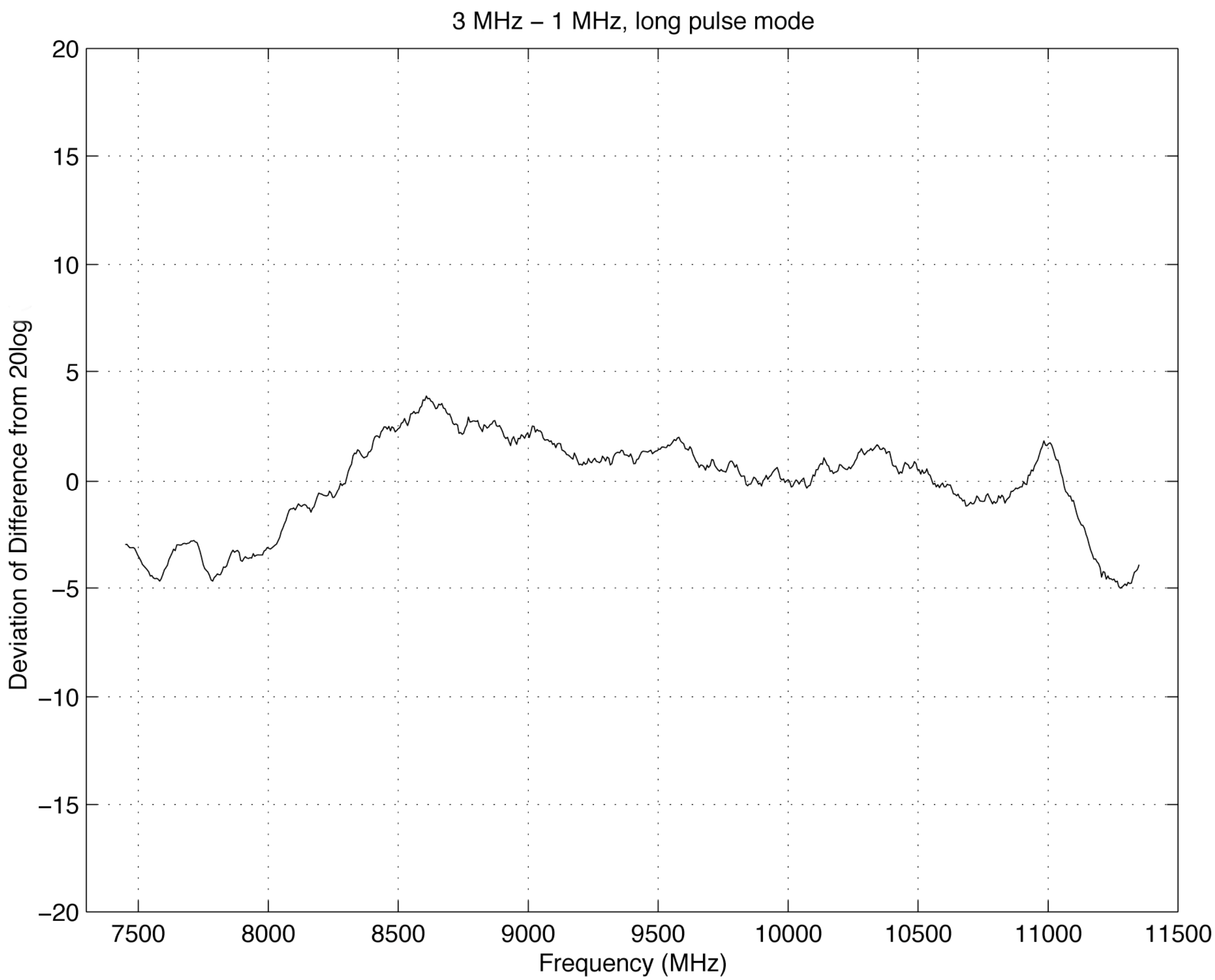
Difference: 1 MHz-300 kHz short pulse



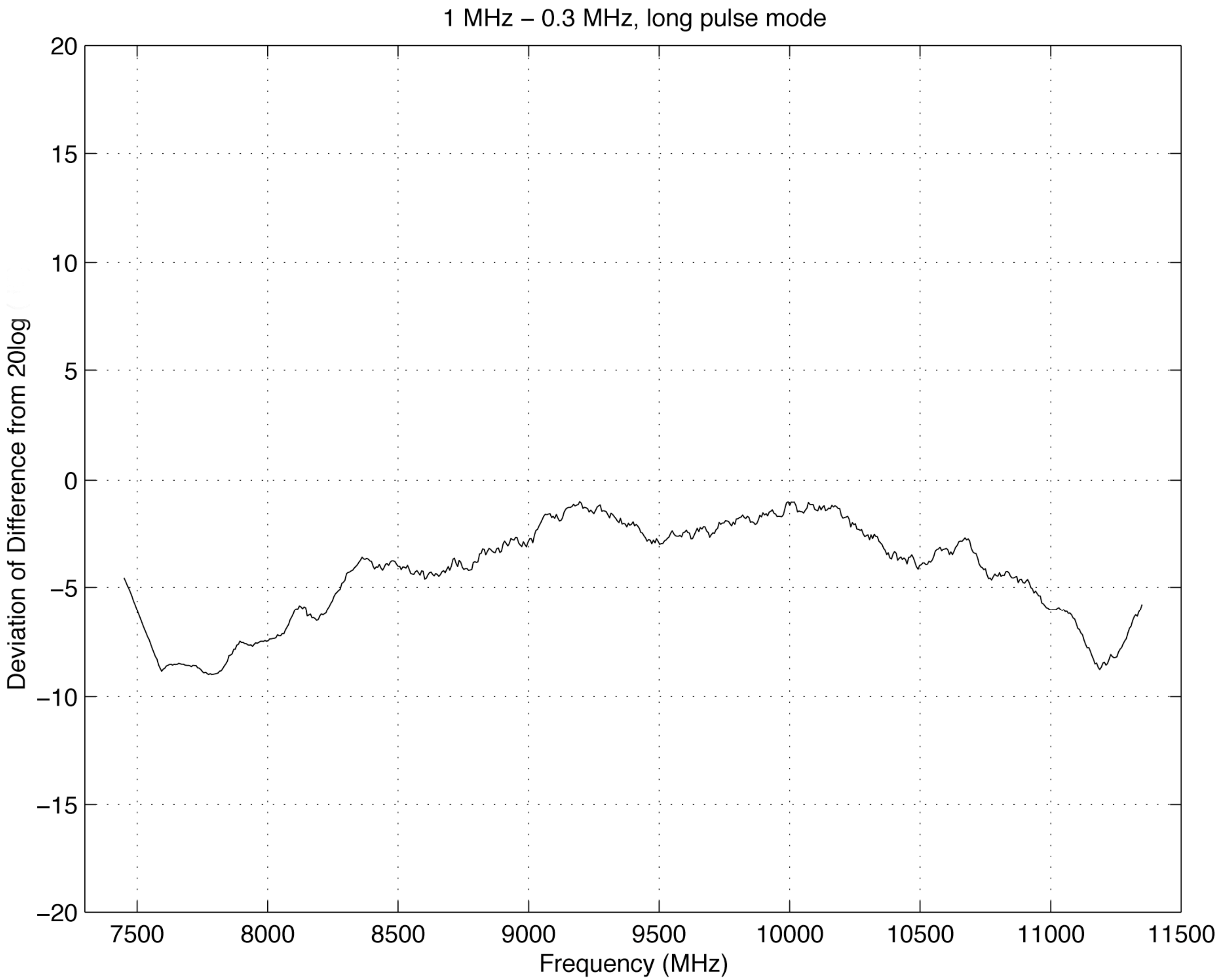
Difference: 8 MHz-3 MHz long pulse mode



Difference: 3 MHz-1 MHz long pulse mode



Difference: 1 MHz-300 kHz long pulse



Summary of Results

Out-of-band and spurious emissions from this maritime radionavigation radar were found to vary at a value typically between **16 log(B_m) and 18 log (B_m).**

(Although extreme coefficient values were as low **12** and as high as **20**)

Preliminary Conclusions

* Radar out-of-band and spurious emissions do not vary as would be predicted for thermal noise (10 log). In this sense at least, they are not noise-like.

* Although the observed variation for this radar is typically closer to 20 log than to 10 log, the spurious emission levels nevertheless typically deviated from 20 log by a few decibels.

* Until this variation is better understood, it might be a good idea for measurement personnel to routinely measure radar emission spectra in several bandwidths. (This is an approach that NTIA has pursued for many years.)

Possible Future Work

- Perform this same sort of measurement on additional radar types. (Also make repeated measurements on the same radar to better understand variation of measured spectra.)

- Undertake study to understand how time-domain features in pulse rising and falling edges affect the OOB and spurious emissions. This would include understanding of their level of *coherency*.

Acknowledgements

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